2-micron Laser Developments for Wind and CO_2 Lidar Applications

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Acknowledgement

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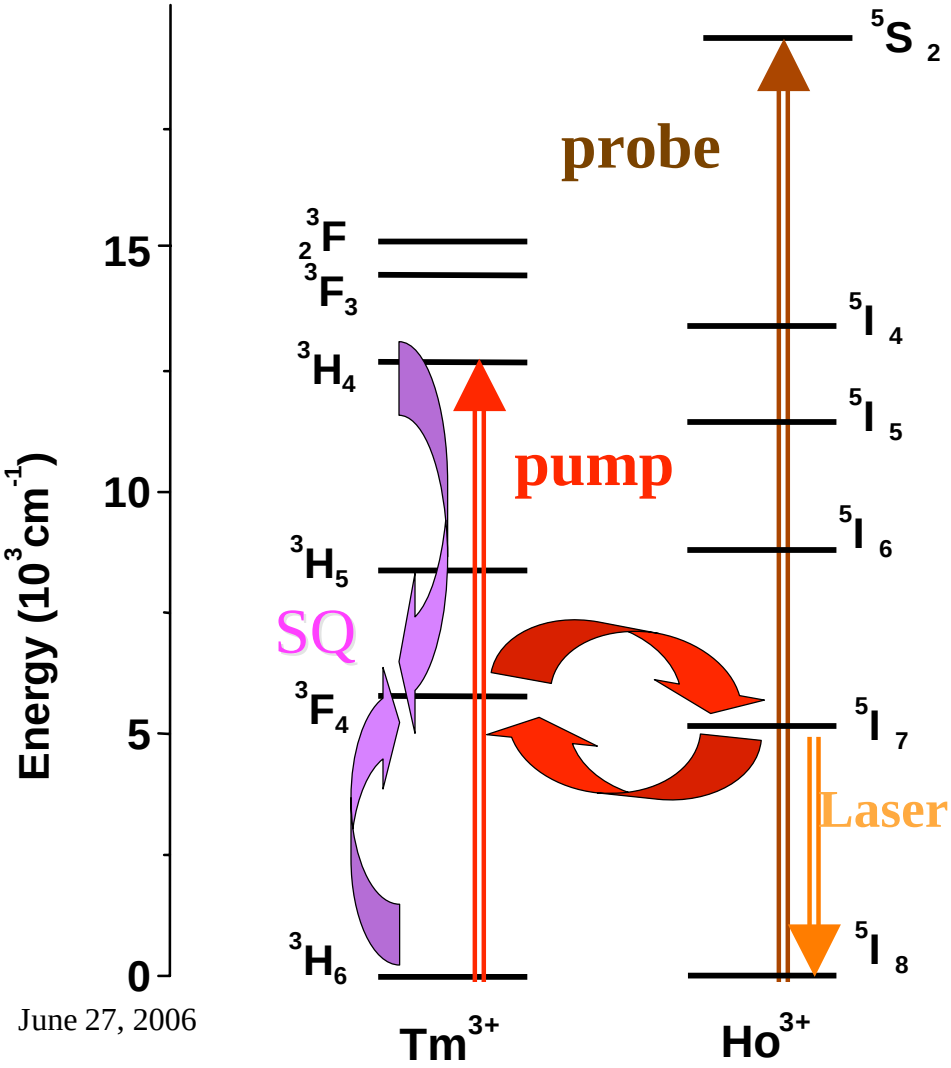
Outline

- Overview 2-micron solid state lasers
- Modeling and population inversion measurement
- Side pump oscillator
- One Joule 2-μm Laser
- Conductively cooled laser development

Solid State 2-micron Lasers

- Tm Lasers (pump diodes 780-805nm)
  - YAG, YLF, $YAlO_3$, YVO_4
- Ho:Tm Lasers (pump diodes 780-805nm)
  - LuLF, YLF, GdLF, YAG, YVO_4
- Tm pumped Ho lasers (pump diodes 780nm)
  - Tm solid state laser pumped Ho Laser
  - Tm fiber laser pumped Ho Laser
- Ho Lasers (pump diodes 1900nm)
  - YAG

Energy transfers between Ho^{3+} and Tm^{3+} ions and Pump-probe experiment



★ **Pump at 792nm ($^3H_6 \rightarrow {}^3H_4$ transition)**

★ **Energy transfers :**

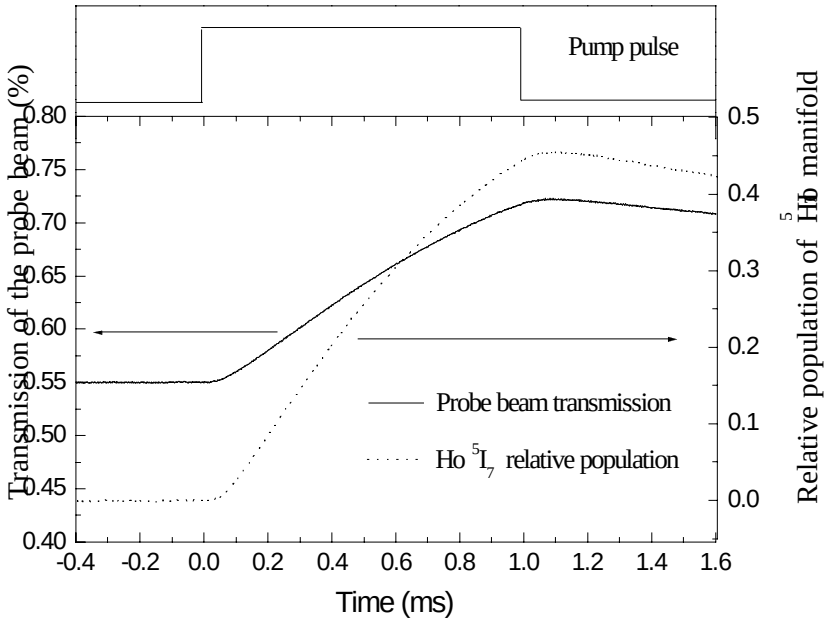
- Self-quenching (P_{SQ})
  two Tm^{3+} ions in the $^3F_4$ manifold
- ($^3F_4 \Rightarrow {}^5I_7$) energy transfer ($P(Tm \rightarrow Ho)$)
- ($^5I_7 \Rightarrow {}^3F_4$) energy transfer ($P(Ho \rightarrow Tm)$)
- Ho , Tm upconversion (P_{UC})

★ **Probe at 543nm ($^5I_8 \rightarrow {}^5S_2$ transition)**

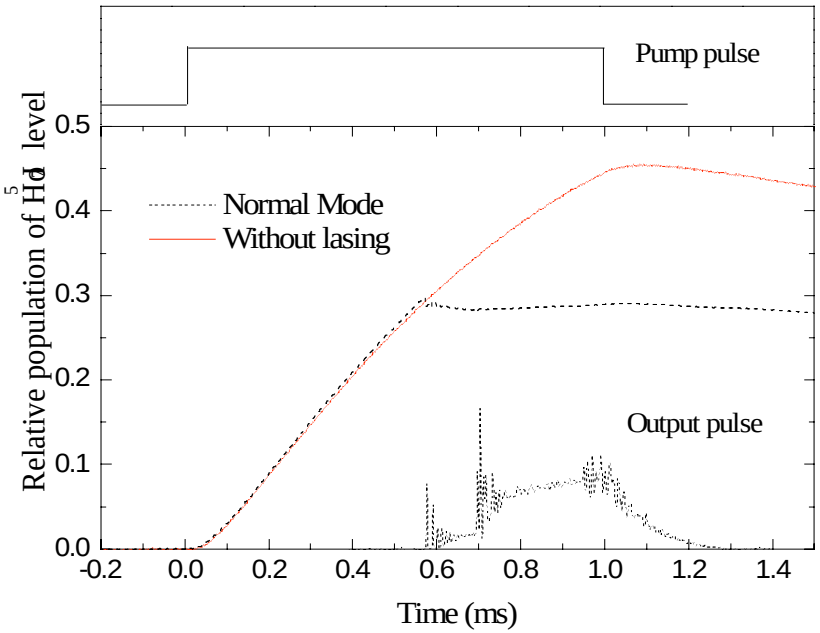
Probe the $^5I_8$ ground-state depletion

Evolution of the probe beam transmission and the corresponding population of the Ho $^5I_7$ manifold

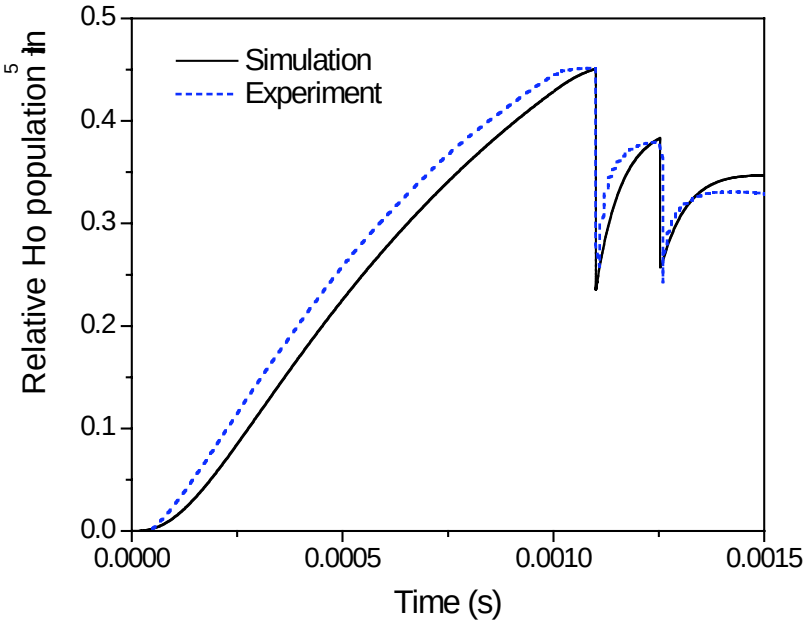
Probe beam transmission and the population of the Ho $5I_7$ manifold

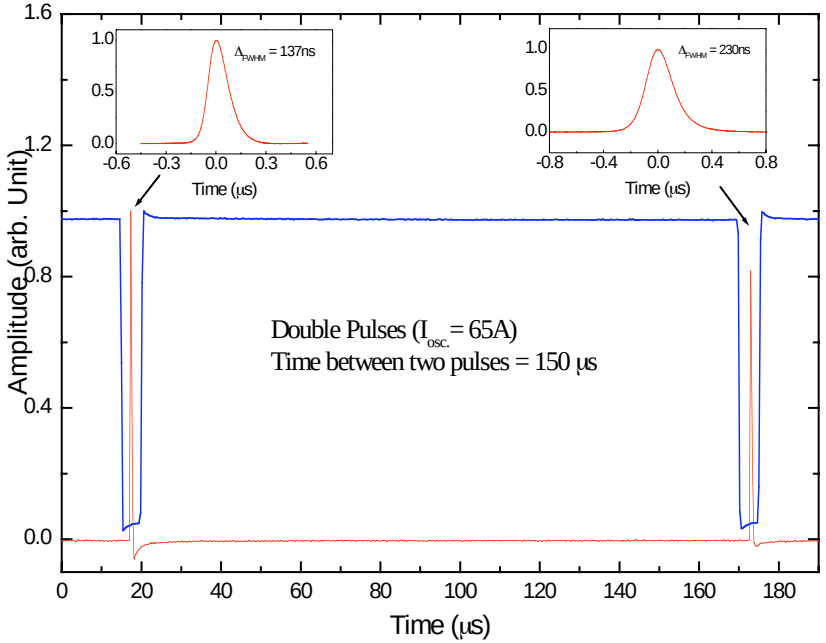


Ho $5I_7$ population at lasing and without lasing condition



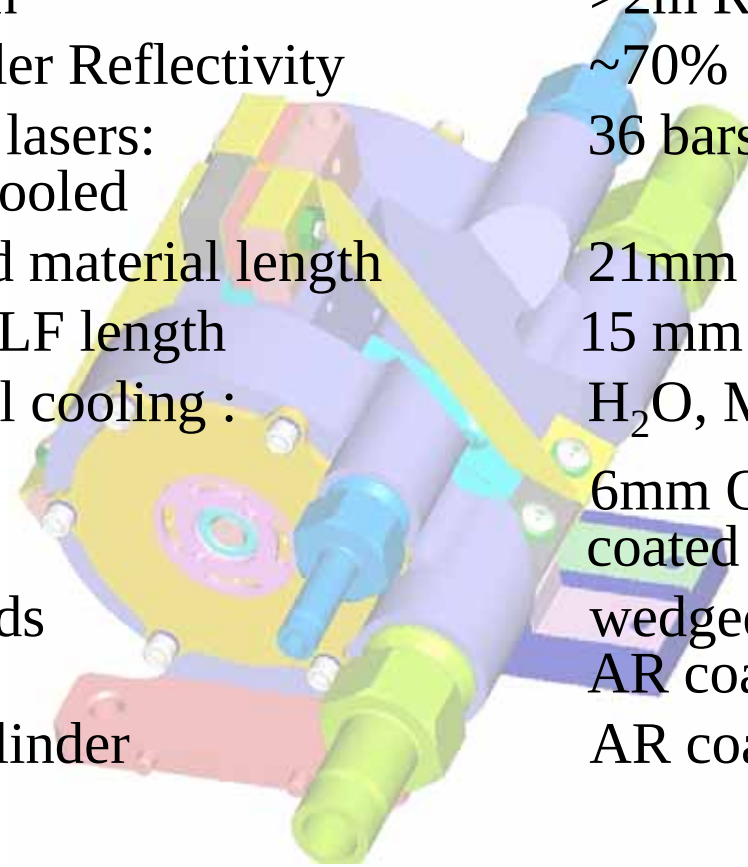
Ho:Tm laser double pulse operation



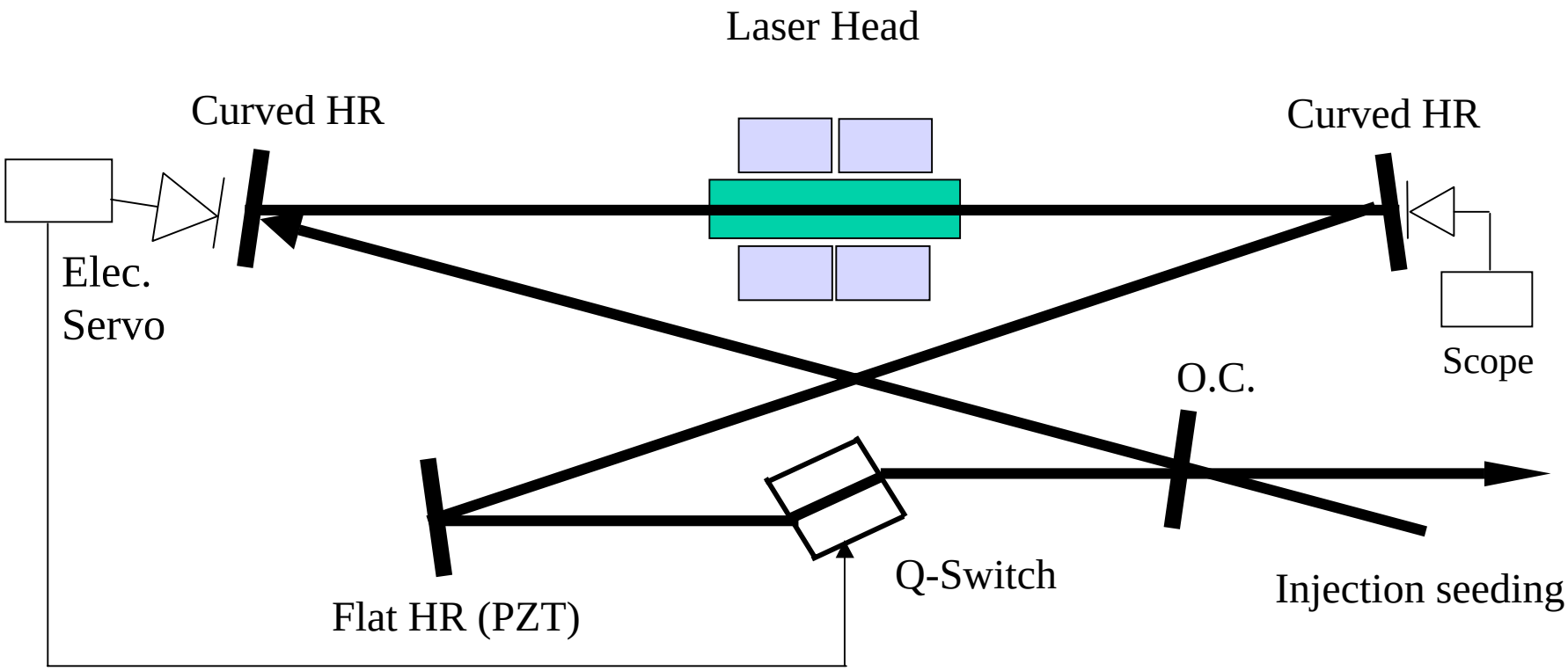


Oscillator features

- Injection seeded
- Cavity length — >2m Ring
- Output coupler Reflectivity — ~70%
- Diode pump lasers: conductive cooled — 36 bars 100W/b
- crystal doped material length — 21mm
- undoped LuLF length — 15 mm
- Laser crystal cooling : — H_2O, Methanol
- Tube size: — 6mm OD 5mm ID AR coated for 792nm
- Laser rod ends — wedged 0.5° along c-axis AR coated for 2.053µm
- Laser rod cylinder — AR coated for 792nm

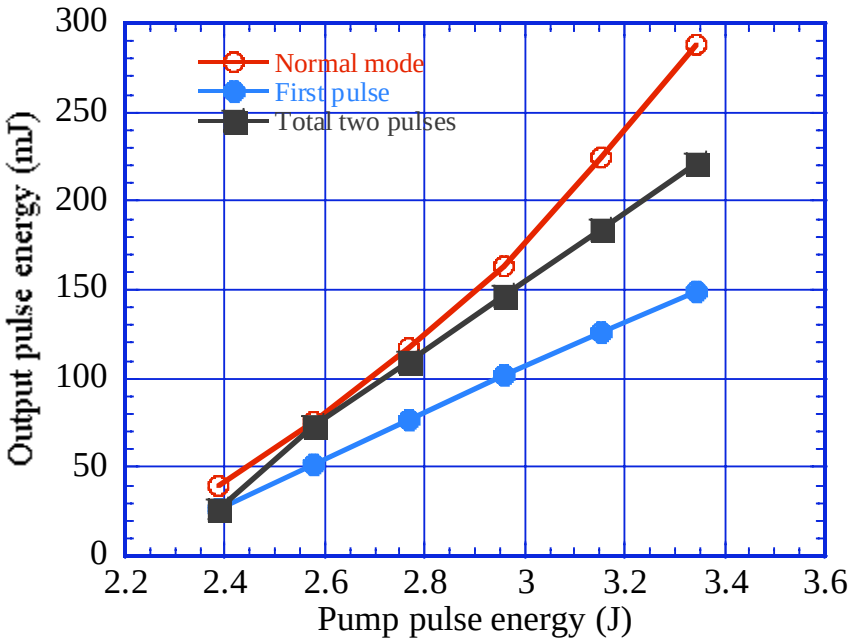


Laser Oscillator Ring Cavity

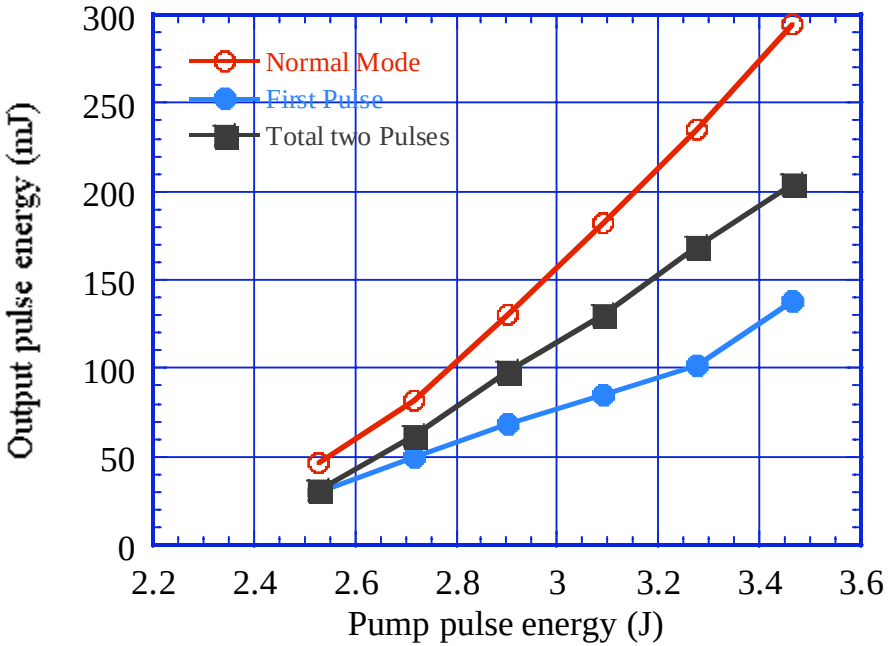


Laser Oscillator Performance

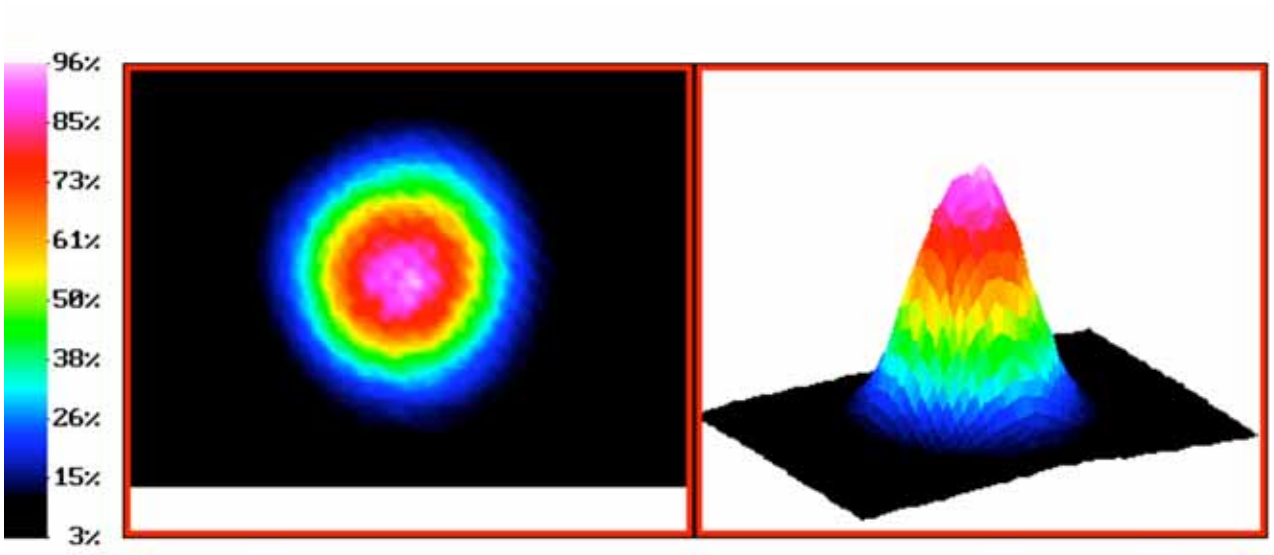
Output pulse energy (2 Hz)

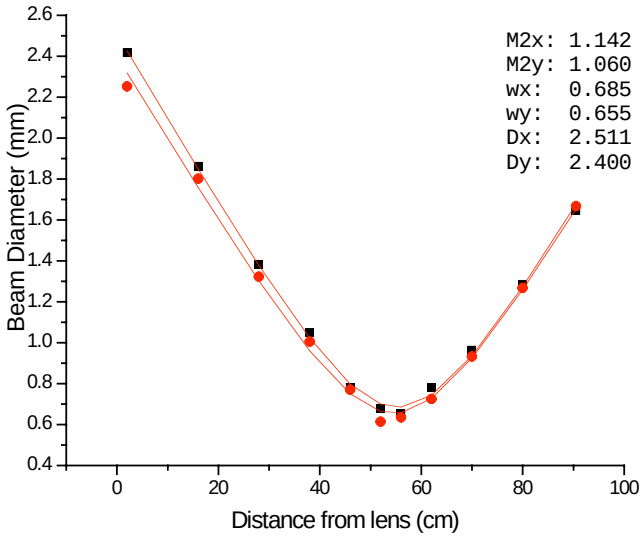


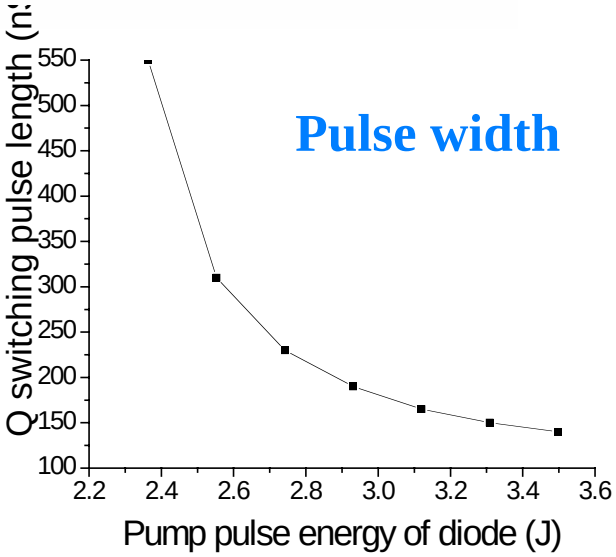
Output pulse energy (10 Hz)



Laser beam profile

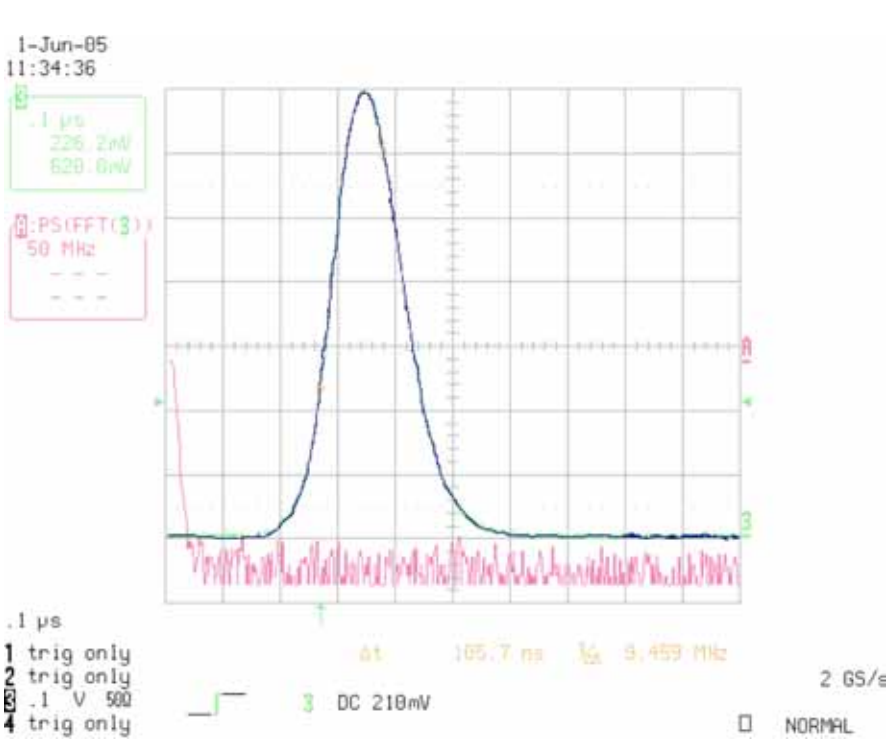


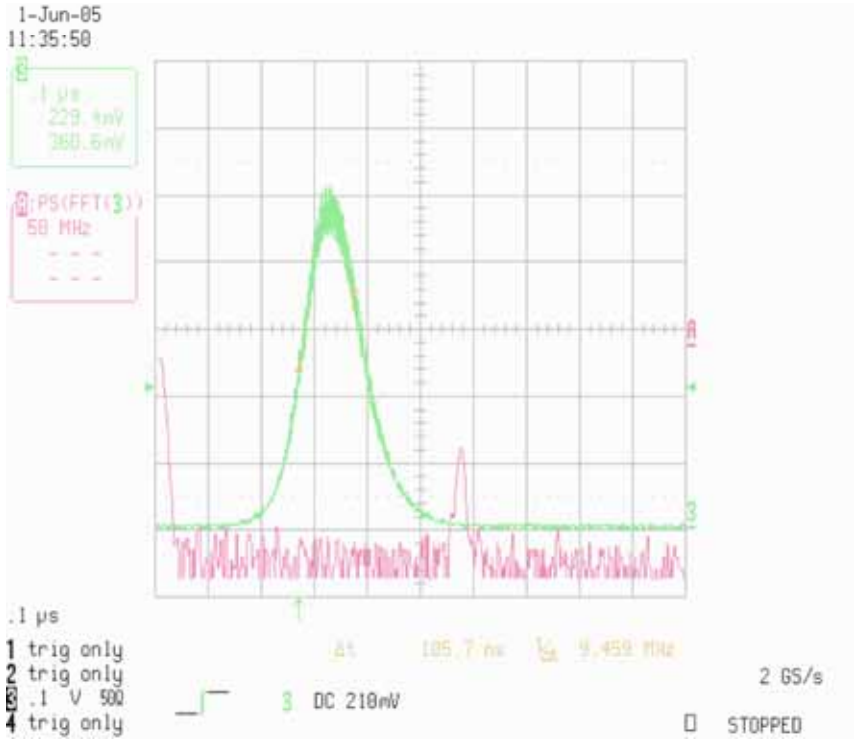




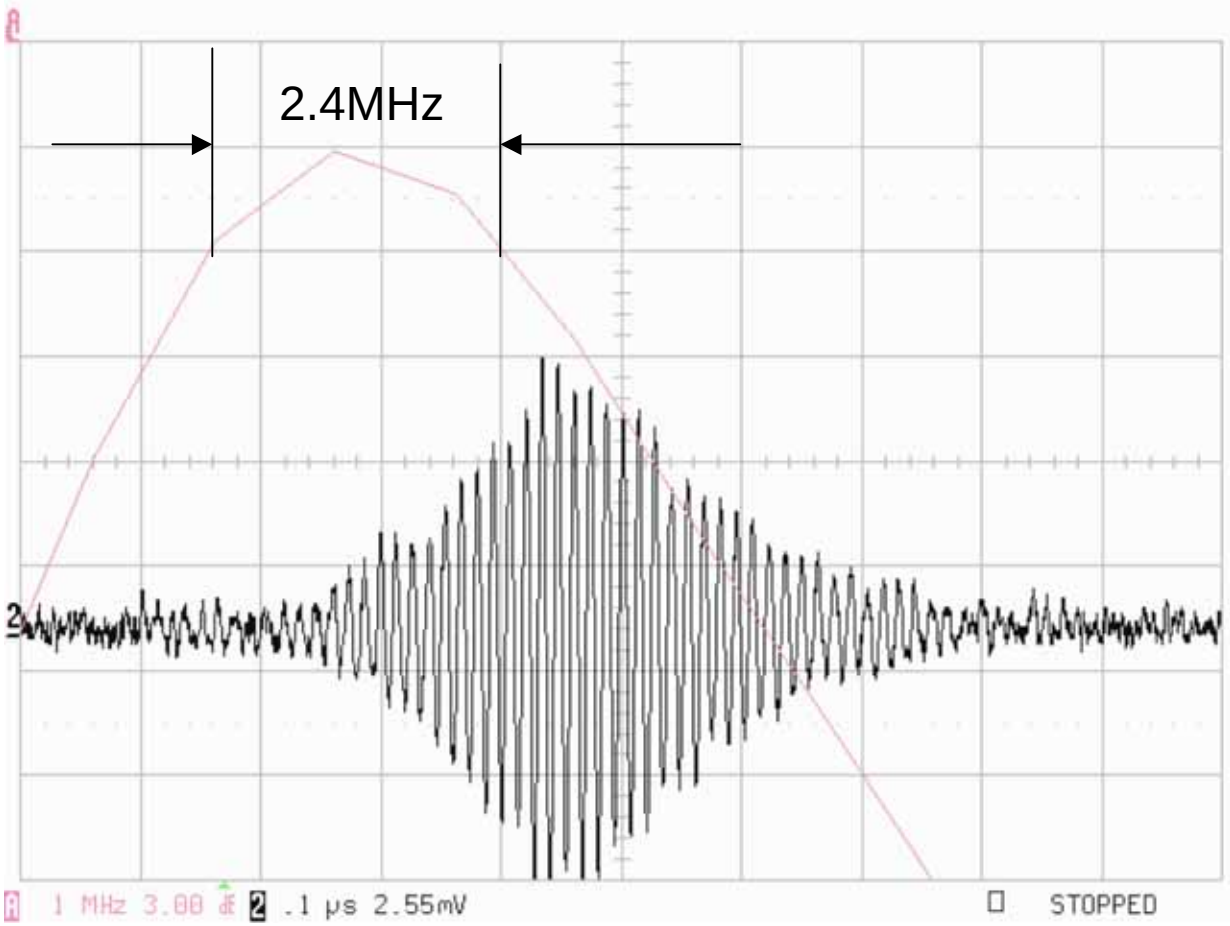
Pulse width

Seeding verification

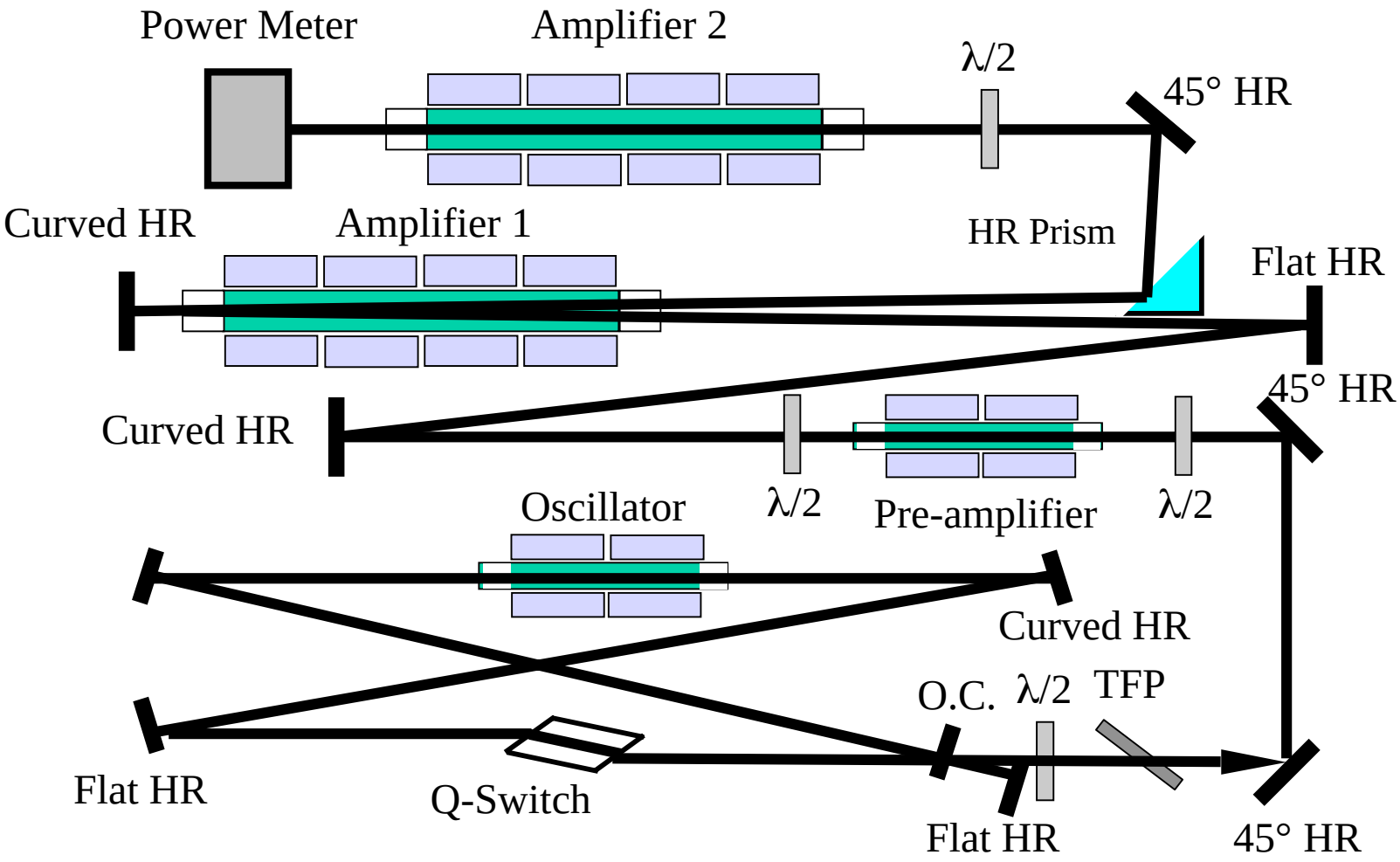




Oscillator line width

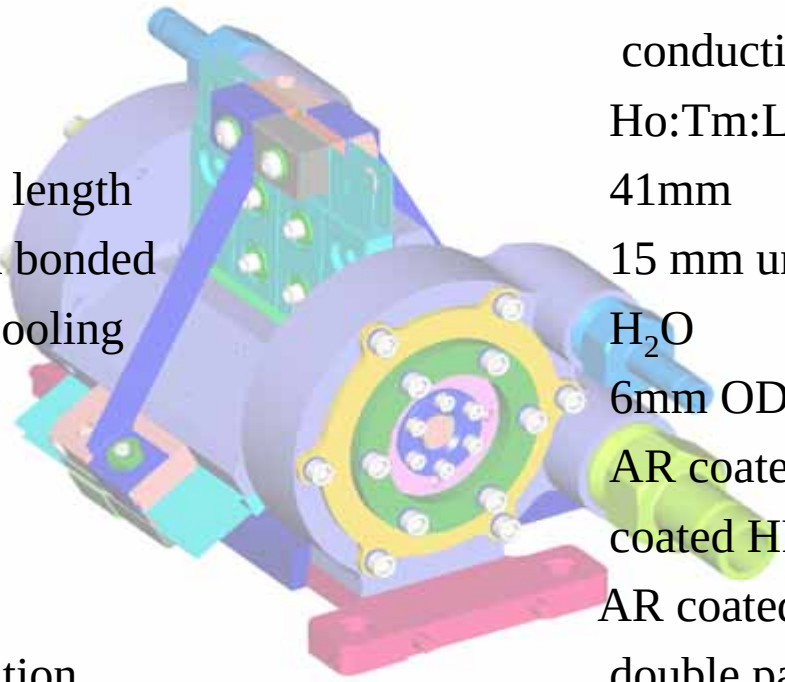


MOPA Experimental Diagram

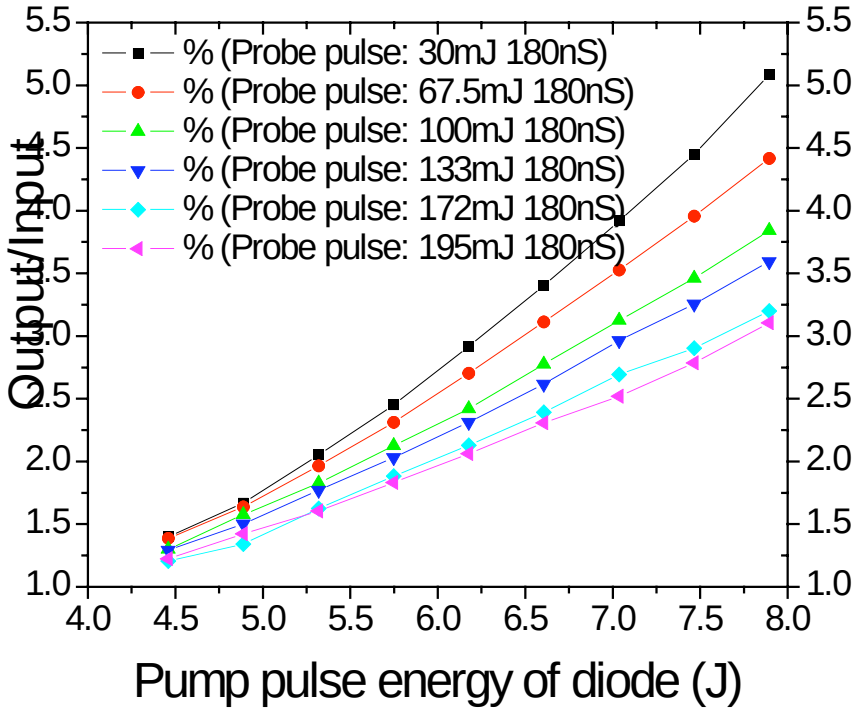


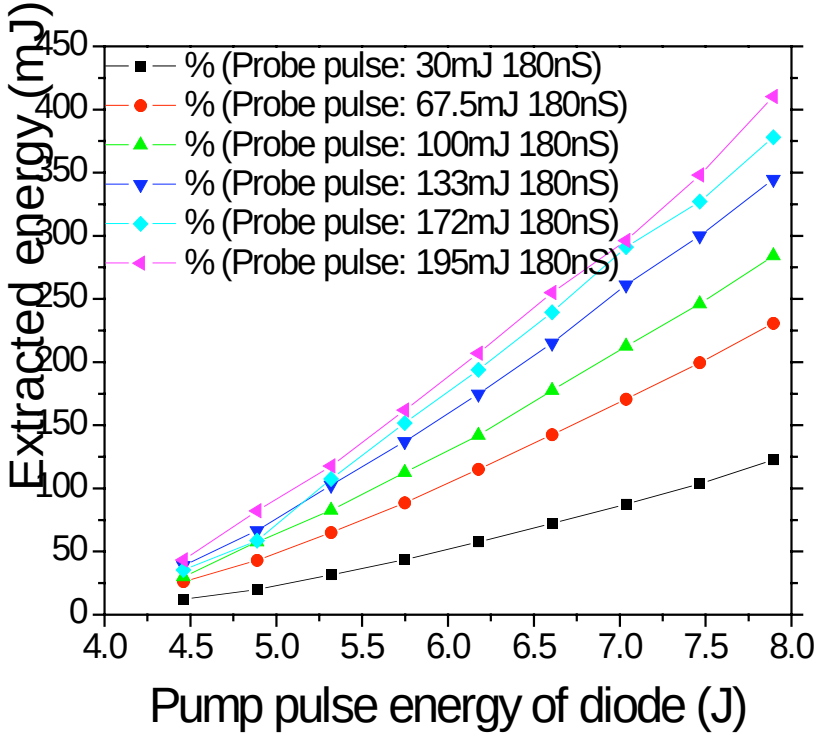
Amplifier features

• Pump energy	7.2Joules12x6 bar arrays with 100watts per bar
• Diode laser	conductive cooled ‘A’Pkg
• Laser crystal	Ho:Tm:LuLF 0.5% Ho 6%Tm
• Doped Crystal length	41mm
• Ends diffusion bonded	15 mm undoped LuLF crystals
• Laser crystal cooling	H_2O
• Flow tube size	6mm OD 5mm ID AR coated 792nm
• One end	AR coated for 2.053µm flat
• Second end	coated HR for 2.053µm flat
• Laser cylinder	AR coated for 792nm
• Path configuration	double pass

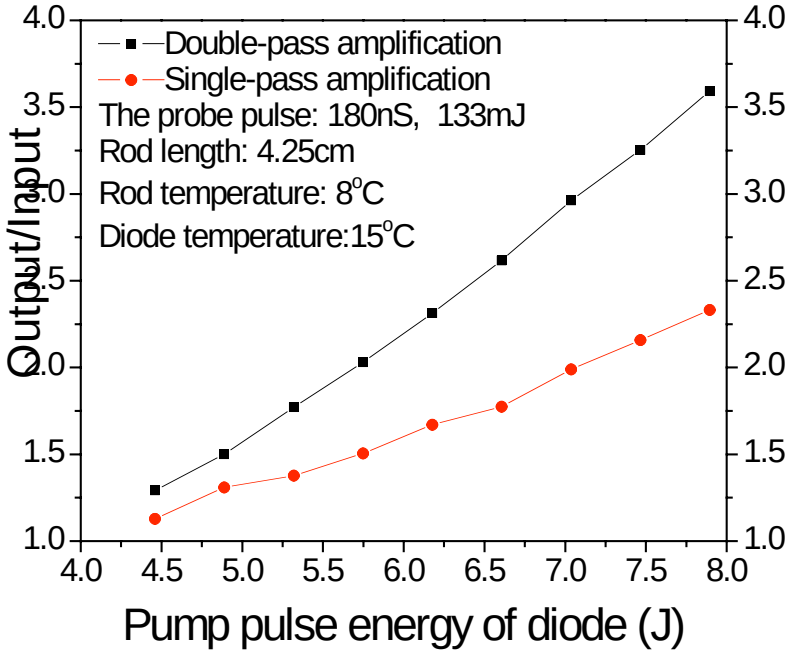


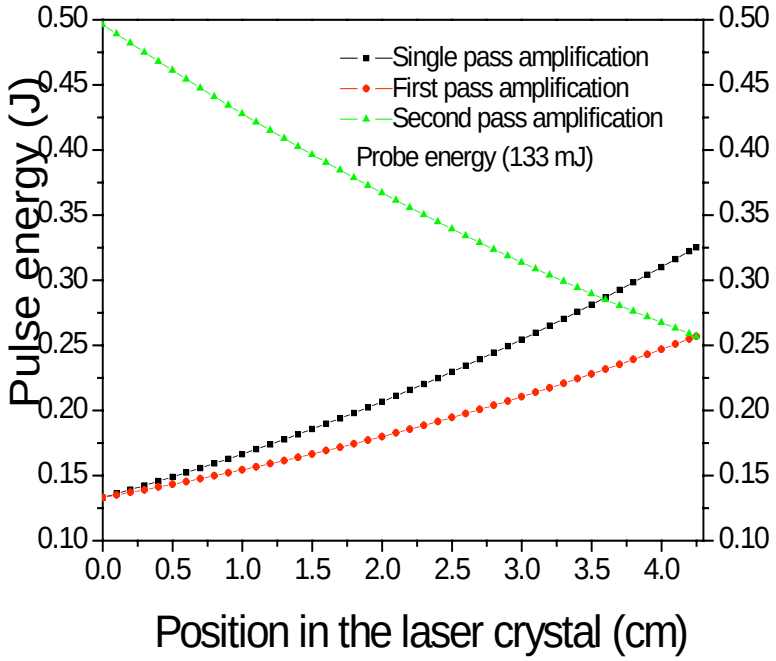
Amplifier One Performances



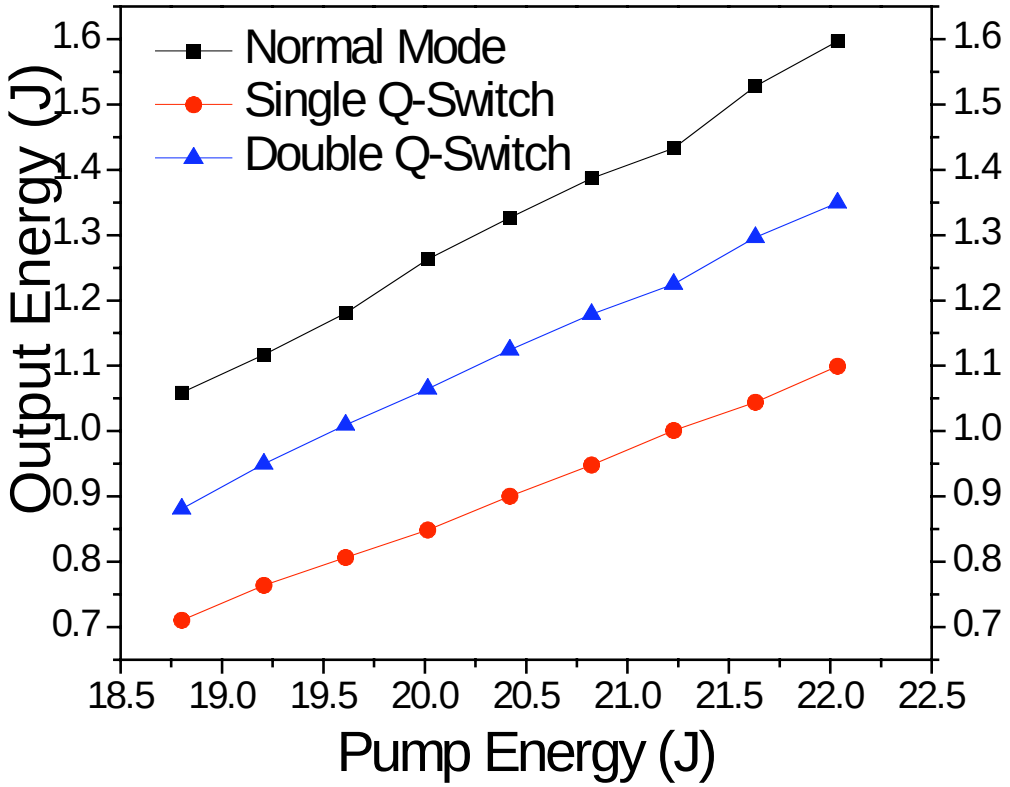


Single and Double Pass Amplification



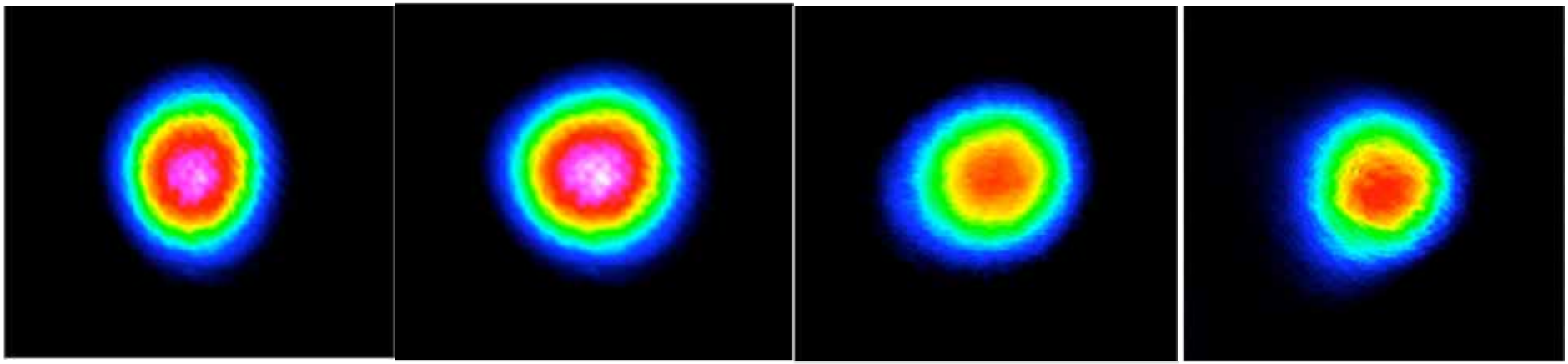


System Performance



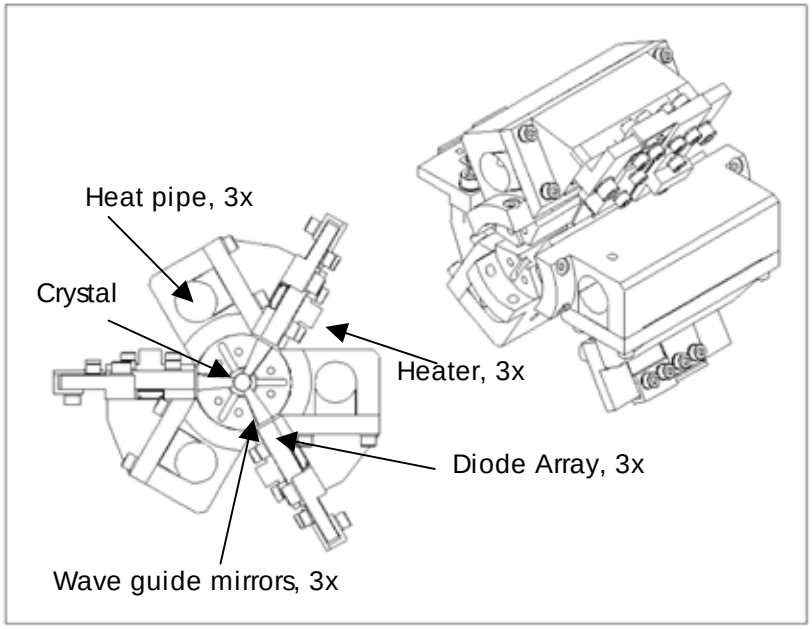
Slope Efficiency: Q-switch 12%

Beam Quality

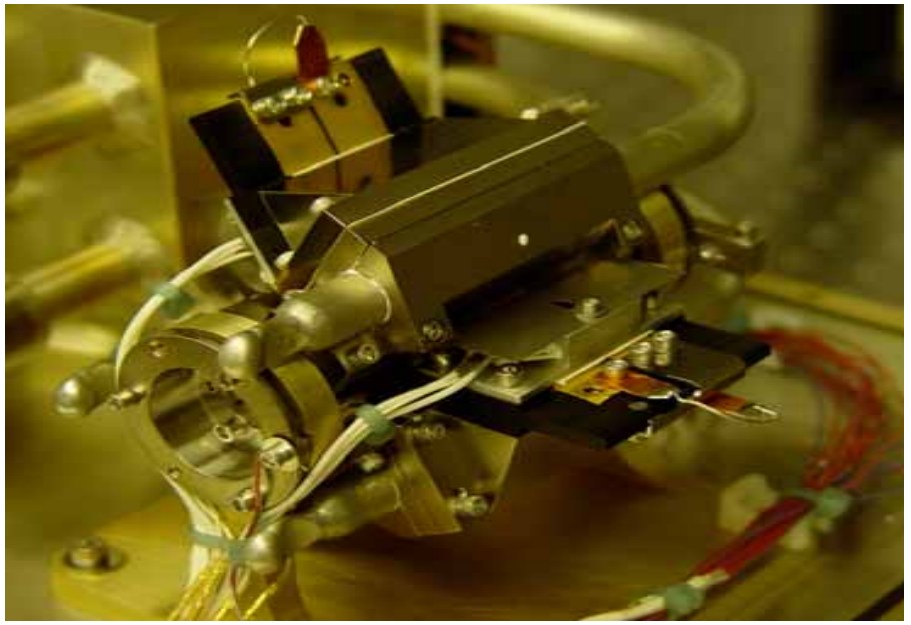


M^2	OSC	PreA	Amp1	Amp2
X	1.14	1.09	1.09	1.44
Y	1.06	1.11	1.22	1.45
Aver.	1.10	1.10	1.16	1.45

CC OSC HEAD

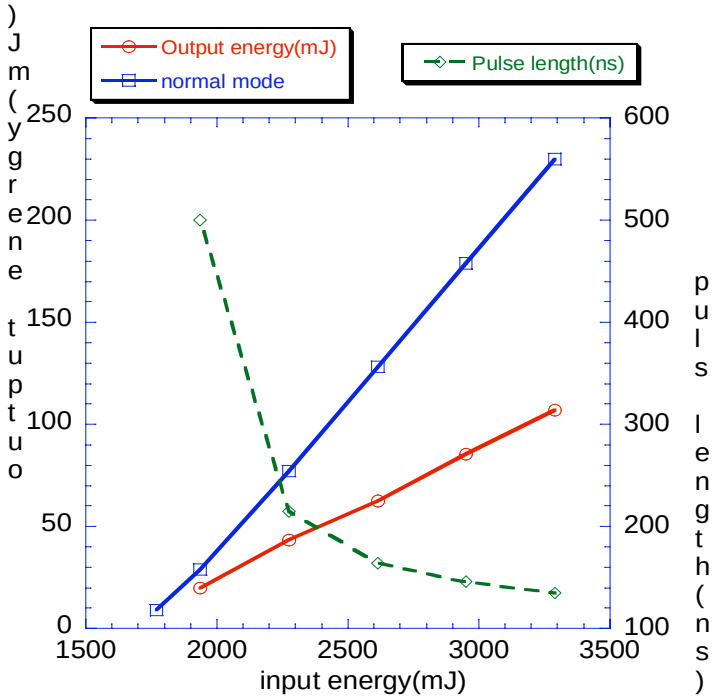


Design of CC Oscillator head

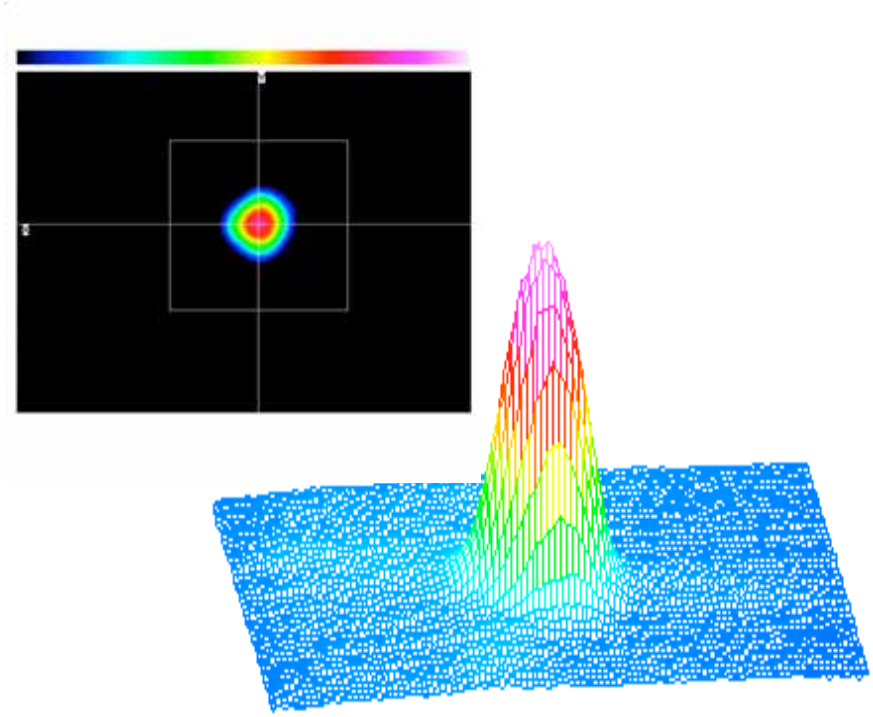


Completed CC Oscillator head

CC OSC PERFORMANCE



At 2 Hz, Q-S mode produced 107 mJ with pulse length of 140 ns



Near field beam profile at 2Hz.
Gaussian with overall beam quality (M^2) of 1.1

Amplifier Design Constraints

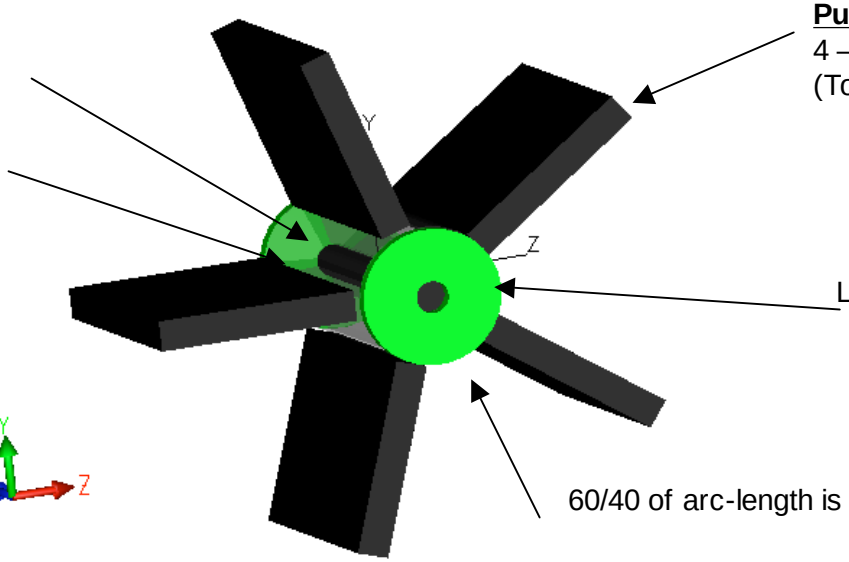
Laser crystal material	**Ho:Tm:LuLF**
Crystal geometry	5mm diameter cylinder x 40mm long
Thermal conductivity	4.3 W/m ^{o}K at nominal 0 ^{o}C
LuLF coefficient of thermal expansion	14ppm/K a-axis and 11ppm/K c-axis
Maximum heat load from crystal	80W
Pump diode laser	**Conductive cooling, 792 nm A-4 diode array**
Average optical power per diode array	4 W at 10 Hz of 1ms pulse width
Diode laser efficiency	40%
Output divergence	40° and 10° in x, y axis respectively
Number of diode laser array per amplifier	20
Total heat load from diode arrays	120W
Thermal transport device	**Ammonia heat pipes (5)**

- Perform optical and thermal analyses within design constraints to guide the mechanical design toward an optimized, robust, and built-able laser oscillator head

5-sided Amplifier Head Concept

Laser Rod (5mm x 40mm long)

Light wave guide



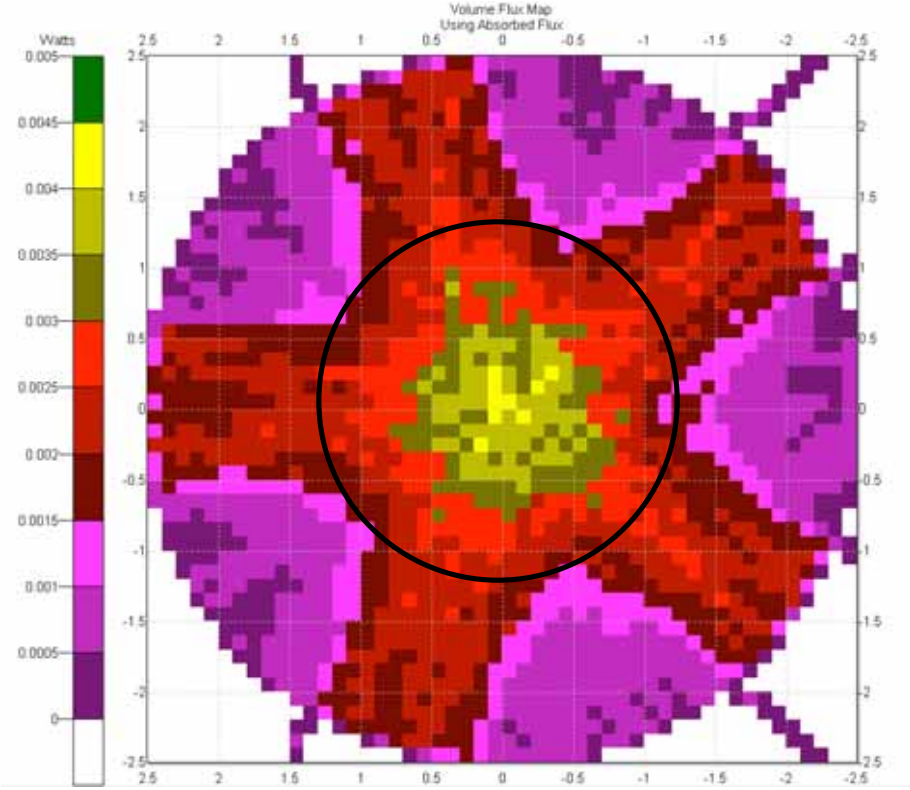
Pump-diode modules, 5x
4 – 4W arrays for 16W/module
(Total 80W pump power)

Laser Rod Housing

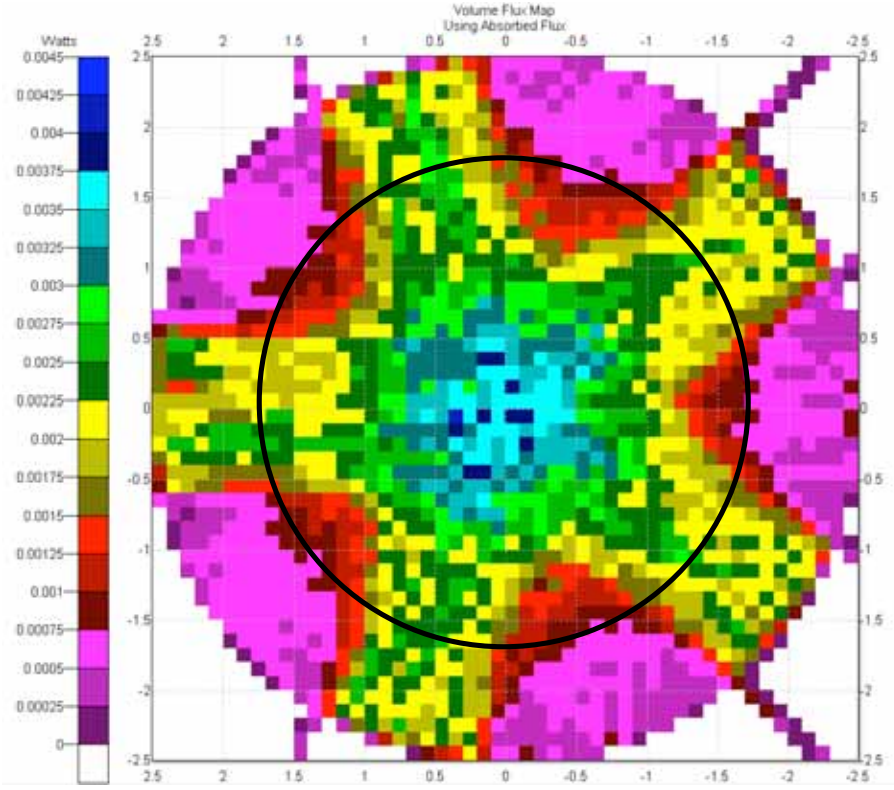
60/40 of arc-length is allocated for conductive cooling

Optical Analysis

- Wave-guide mirrors optimization



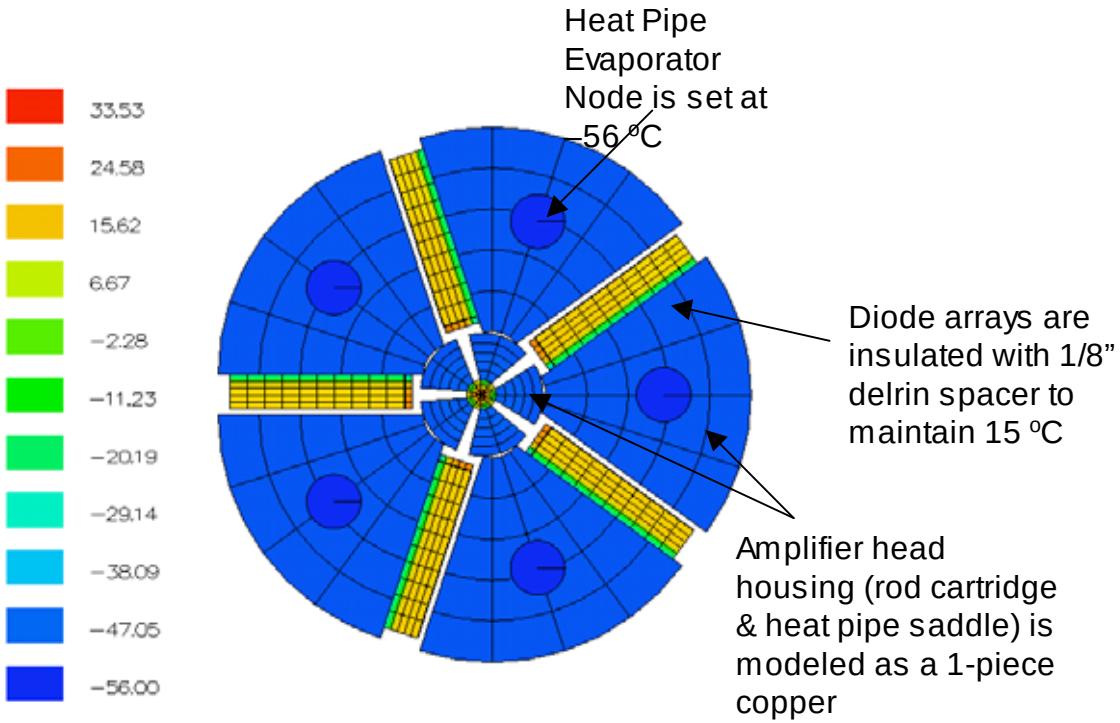
(a) Wave-guide facet angle is 7.3^{o}
Beam diameter is 2.5 mm



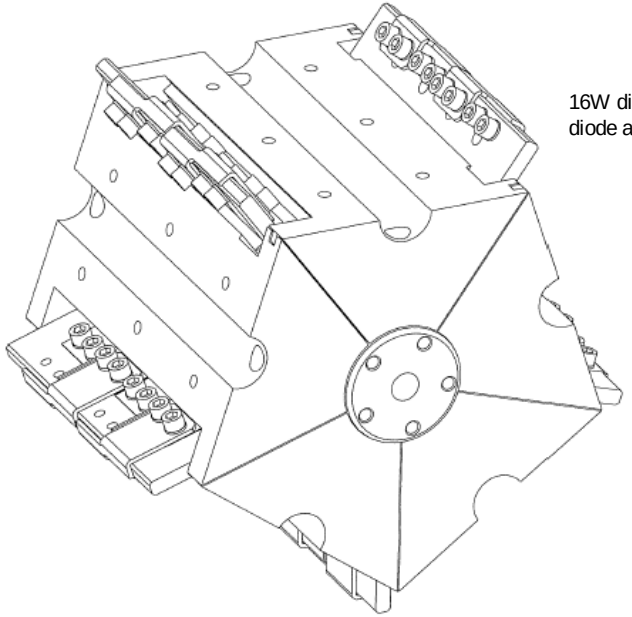
(b) Wave-guide facet angle is 10.0^{o}
Beam diameter is 3.5 mm

Final Amplifier Head Design Over-all Thermal Map

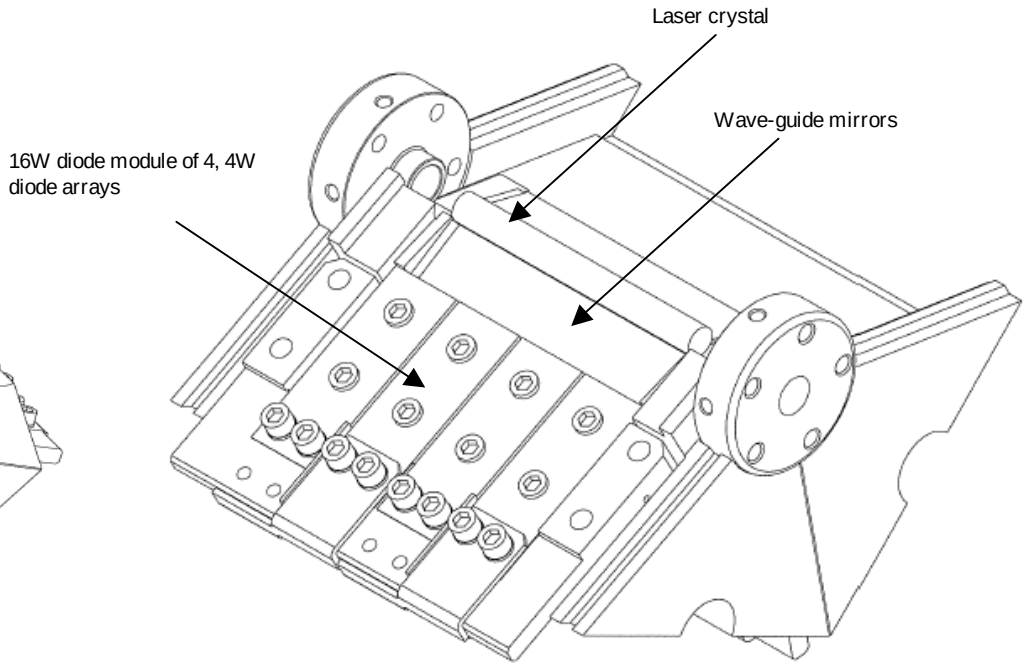
- Tradeoff studies were performed to optimize amplifier housing for minimum thermal gradient
- Optimization parameters included physical geometry and material selection.
- Optimized solution is to combined crystal cartridge with heat pipe saddle into a single piece amplifier head housing make from copper



CC Amp Head Detail Design

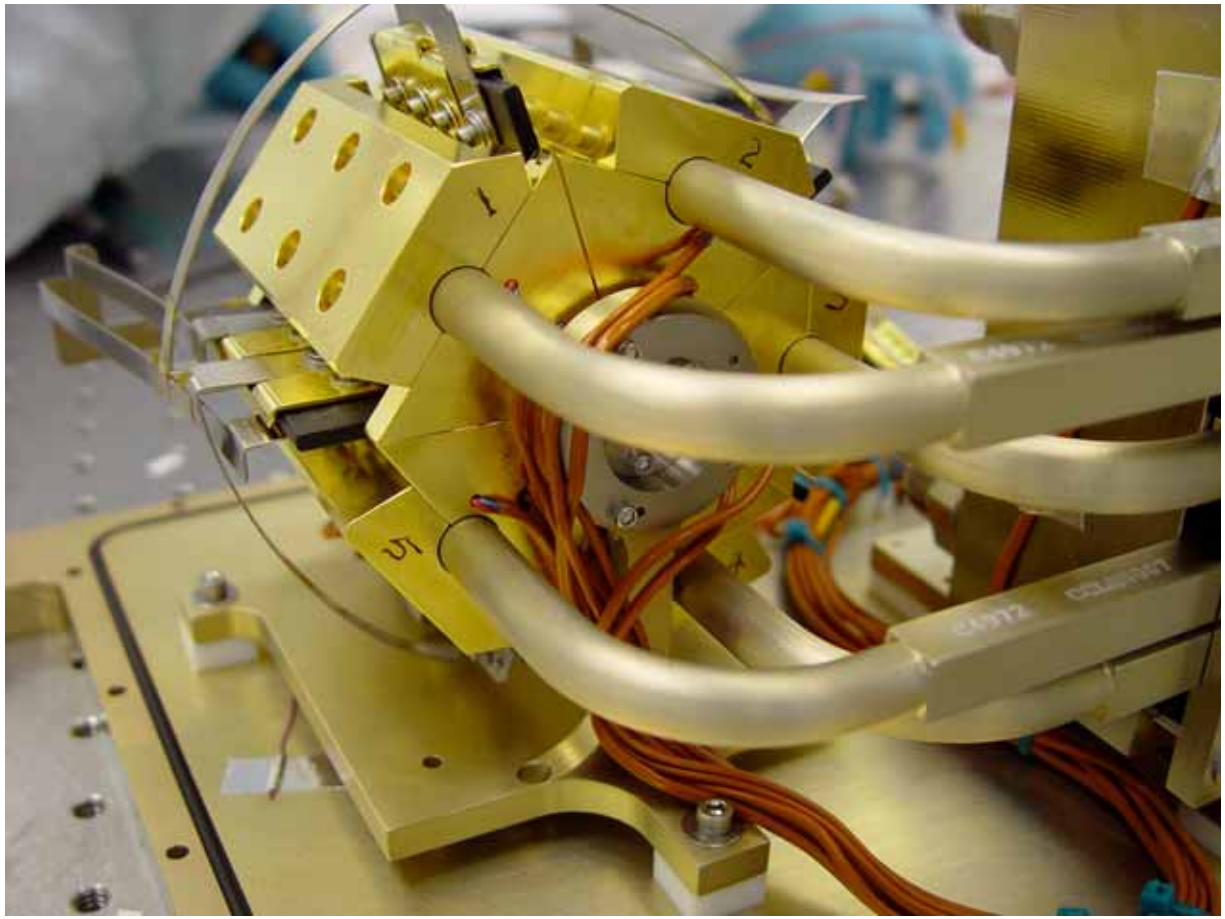


(a) 5-sided, 1-piece amplifier head

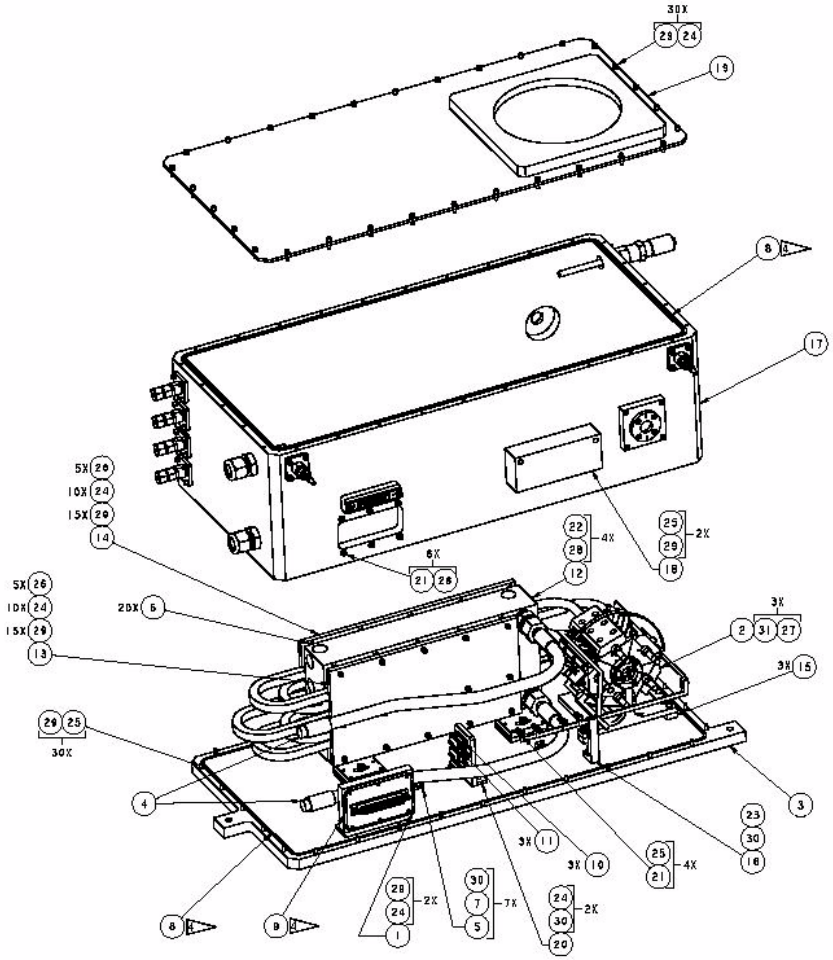


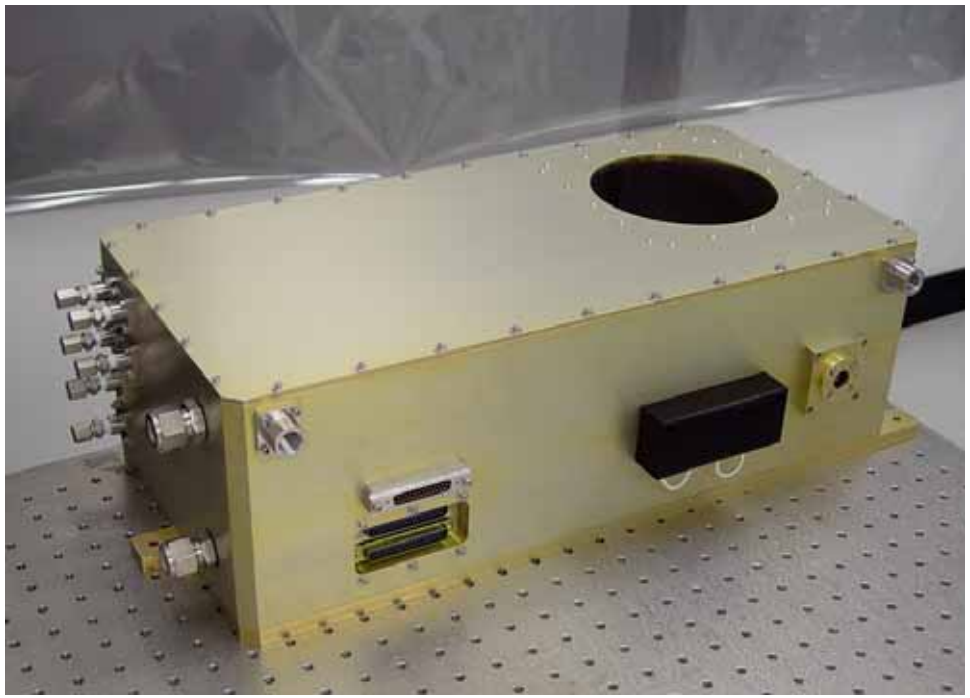
(b) Cut-away view of amplifier head

CC amplifier Head



CC Amp Assembly





Conclusions

- We have successfully demonstrated, for the first time, a high energy 2-micron laser that breaks one Joule per pulse barrier.
- We have demonstrated a diode-pumped, totally conductive cooled, Q-Switched, 2-micron oscillator, which enhanced the technical readiness level of the instrument for space qualification.
- We developed a totally conductive cooled 2-micron amplifier